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Unit 1 Overview

Exercise:



Problem:

Things to Consider as You Read:

- This section provides an overview of the first unit on mathematical tools and foundational concepts for Physics 131; we will be using concepts from this unit throughout the class.
- There are also a few hints and tips in the section on how to do the homework efficiently; I would suggest developing good homework habits early.
- This overview is also available as a video here, or on Youtube at <https://www.youtube.com/watch?v=ikLsqv2dhY8>.

In this unit, we will explore some of the fundamental mathematical tools and basic concepts that we will need throughout the rest of the course in our study of physics, including:

- An introduction to what physics is as a discipline and how that might be similar to or different from some of the other sciences you may have studied,
- A review of the basic idea of units
- My policy on significant figures
- Introduce the basic ideas of mean and standard deviation for use in the laboratory exercises within this course
- The definition of displacement, velocity, and acceleration; in particular, how velocity and acceleration are similar to and different from distance and speed
- How to use iterative methods to predict the motion of objects that move with non-uniform acceleration

General Notes About Homework

The homework in this course is intended to provide you with some basic information. The material in the preparation will be the starting point for what we discuss in class. This helps to make sure that everyone with their varying backgrounds in physics is starting at the same point. We will then build upon this preparation in class, using in-class activities to get you ready for exams. This is somewhat different probably from your other courses where the purpose of the homework is to provide additional practice on in-class material to help you get ready for exams. **In this course, the homework gets you ready for class, and class is what gets you ready for the exams.**

How to be Successful

Each homework is divided up into sections. Within each section, the first question is your readings to do for that particular section, followed by a set of problems. The information you need to complete a set of problems will be in the readings at the beginning of that section. The readings are presented in terms of a checklist. This problem is not for a grade, it's just presented as a checklist to make sure that you get everything done. So, you may have various readings within the OpenStax textbook UMass edition which is on Perusall, and you may also have some videos. The videos are embedded directly within the online homework system, and you should be able to play them right there, but if you cannot, you can go and click this [link](#) and it will take you to the course YouTube page, and you can watch the videos there. The transcripts for all of the videos are also included in the textbook themselves, so if you want to go and read the text because you prefer to read or you want to add some sort of Perusall comment to some of the content of the video, you can do that within the textbook in Perusall, so each video has an associated section in the textbook and in Perusall with the transcript of that video for you to comment.

Once you've completed the readings, you're now ready to move on to the actual homework problems. These problems are there to help you check that you understood what was in the various readings and videos, and to

help you refine your understanding. Most of the individual parts of each problem are one-step. If you find yourself doing long chains of calculations, come get help in the consultation room. You're probably approaching the problem in a way that's not very efficient. When doing the homework, don't skip the readings and the videos. Your comments on the actual readings in Perusall are graded in accordance with the policy in the syllabus and form a part of your homework grade. We acknowledge that doing all of these readings and all of this homework is hard work, and we are here to help; we've provided quite a few resources to help you be successful in completing this assignment. Moreover, since it is so much work, the preparation is your entire homework for this course. There is no required end of chapter homework assignments; you only need to do this preparation. This is your big focus for your homework.

What to focus on in the Unit 1 Preparation Homework

I want you to focus on, while doing this homework, the definitions of the terms **position**, **velocity**, and **acceleration**, the few basic equations such as $\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t}$ and $\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t}$, including what all the symbols mean and when these equations can be applied. Many people in studying physics for the first time understand they need to know what the symbols mean, but they tend to skip over this second element, which is just as important, if not more so, because not every equation can be applied in every situation. I will also ask you to learn how to just "turn the crank" for various types of calculations, such as iterative calculations. Don't worry if you don't really understand what you're doing when you do these calculations. If conceptually it doesn't make sense, that's okay; we will spend time in class working with these ideas and getting an understanding of what you're doing. I just want you to know how to do these calculations.

Finally, I would like to have a quick philosophical comment regarding motion with constant acceleration. If you have had any physics before, you may have seen the so-called kinematic equations, which are these two here:

$$d = v_0 t + \frac{1}{2} a t^2$$

$$v^2 = v_0^2 + 2ad$$

We will NOT be using these equations in this class. We will be approaching the subject, and many others, in ways that may be different from how you may have seen them in a previous physics class. We believe that physics is not about memorizing equations and learning how to piece those equations together. We believe instead that physics is about fundamental ideas, and we will teach this course from this perspective. Occasionally, this will result in physics homework very different from what you may expect. A good example is the homework for the second unit, where you have some actual fill-in-the-blank type of questions. If you try to learn physics as a set of ideas instead of a set of equations to be pieced together, and start your analysis of situations from fundamental physical principles, then your physics experience will enrich and enhance your understanding of your other courses, as opposed to just being a course that you just “have to take for your major”.

Unit 2 Overview

Exercise:



Problem: Your Quiz will Cover

- Calculating the magnitude of each force under a variety of circumstances using Newton's second law ($F = ma$)
- Categorizing these forces as contact/field, fundamental/constraint/empirical
- Contrasting the properties of fundamental forces, constraint forces, and empirical forces

In the chapter, we're going to be moving beyond these ideas in the previous two chapters, and building upon them to talk about the question "why does the motion of an object change?".

I want to draw your attention to two particular points: we're moving from describing how objects move to why objects move, and the question is why does motion change, not what causes motion. These are subtly different questions, and the difference between these questions is really at the core of the laws of Isaac Newton, that form the core of this course. So, we're switching from describing how objects move to why does motion change.

This is a more significant switch than it might first appear. Consider the case of a falling object. For millennia, people explained that objects fall using the logic of Aristotle. Aristotle posited that the natural state of an object is to be at rest on the surface of the earth. This explanation seemed to fit all observations at the time, but lacked any mechanism of why this was the case. In modern terms, we would call this a phenomenological description of what happens. It says, "things fall, it's the natural state of them to fall, we don't really know why, just that they fall". It's a phenomenological description without any description of mechanism on

why do things fall. And without an understanding of mechanism, we can run into trouble.

For example, the New Horizons space probe that has just visited Pluto and is currently on its way out of the solar system is clearly not going to come to some natural state of rest on the surface of the earth. It's going to keep going forever. Moreover, this switch from description to mechanism is a huge part of the exciting developments in the life sciences that are taking place right now. A lot of the life sciences are really starting to move into mechanism, and it's leading to some interesting and exciting science. We'll look a little bit more at the difference between phenomenological and mechanistic descriptions in some readings from the University of Maryland, as well as in the introduction to chapter four in the OpenStax textbook.

So, why does motion change? In a word forces. Forces cause motion to change. This is one of the key points for this entire course. Now, this idea might be counter to your everyday experience. In our everyday experience, it seems that forces cause motion. For example, if the cabinet is sliding across the floor, I have to keep pushing to keep it motion, I have to keep applying a force or the cabinet will stop moving. So, in our everyday experience, it seems that forces cause motion, but it turns out that this is not true. Forces don't cause motion, forces cause motion to change, and this difference between our everyday experience and the real laws that govern the universe is because our world is very complicated. In the example of the cabinet, the friction between the cabinet and the floor is complicating and impeding our understanding. To get a true feel for what's going on, we need to remove all the complications of our real world. So, let's think about removing complications. This idea, which is explored more in OpenStax chapter 4.2, is critical to physics, and is becoming more of a feature in other sciences like biology. As these Sciences begin to look more and more at mechanistic explanations, the idea is to strip away all the complications from the world and think about the simplest possible world. A classic example is the world without any friction and without any type of air resistance. Then, thinking about this world, you figure out what laws apply, then once you've figured out what the fundamental laws are, you can add the complications back in.

So, while we'll spend a lot of time in this class talking about worlds without friction and air resistance, I want you to know that this idea has worked very well, and has developed a very strong set of fundamental physical laws, and these fundamental physical laws do translate to your other courses. The laws of Newton that we're going to study in this course are the fundamental laws that every other science course you ever will take must obey. Evolution is constrained by the laws of physics. Chemistry is constrained by the laws of physics. They're just these other complications that we strip away in this course, but get added back in, so learning to think in a way of removing complications and adding them back in is one of the key goals of this course. So, what do forces do? Forces cause motion to change. If you get nothing else from this class, I want you to get this idea that forces cause motion to change. In- class we will do some practical exercises to further develop this idea.

Unit 3 Overview

Exercise:



Problem: This overview is also available as a video [here](#).

What is the meaning of the title of this unit? Well in our last unit, we introduced the ideas of forces and Newton's laws, and while forces are sufficient to determine the acceleration, there are clearly other quantities that are interesting if we stop and think about it. For example, it is easier to open a door by pushing on the door on the far side from the hinge where the knob is located than by pushing on the door near the hinge. If you've never really thought about this while opening a door, I encourage you to go try it. Similarly, if I apply a force to a ball for a short time, I get a different result than if I apply that same force for a long amount of time. If I apply the force for a long amount of time, the final velocity of the ball will be larger. For these reasons, we will be exploring in this unit forces in conjunction with other quantities. All our principles from the last unit still work, and many of these situations could be analyzed solely within the context of Newton's laws if you need it to. However, the new ideas we're going to introduce in this unit are often simpler to think about and to work with. However, with all the new concepts, choosing which concept to apply in each situation becomes its own unique challenge.

So, let's do a quick overview of the different concepts we're going to talk about in this unit. The first unit we will discuss is torque, and this is the fact that where forces are applied can matter. So, this goes back to the door; applying a force near the hinge results in a different experience than applying a force far away from the hinge at the knob. The next quantity is impulse; how long we apply a force also matters. We will also introduce the idea of pressure. Pressure is the fact the area over which the force is applied can matter. This quantity is particularly relevant when we discuss fluids, which, remember, include both gases and liquids. The final quantity we will

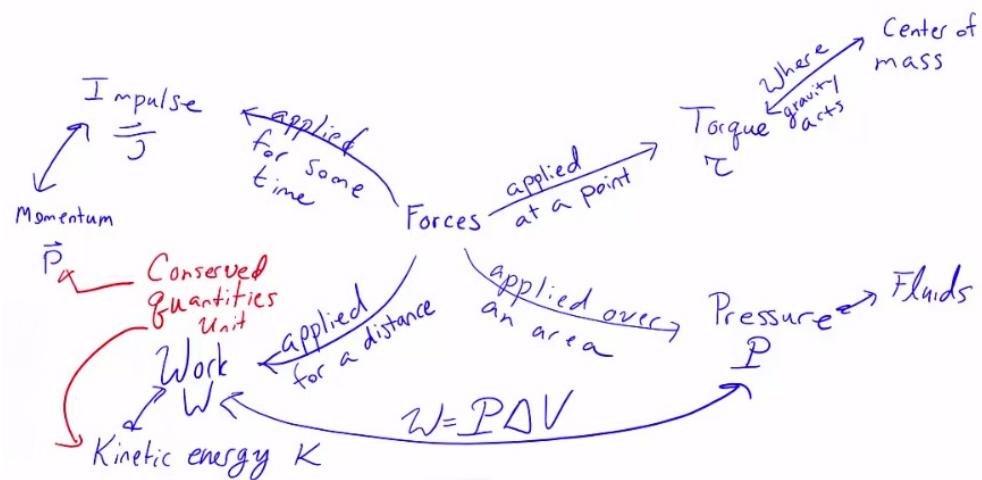
discuss in this unit is work. Work is the fact that the distance over which the forces applied matters. If I apply a force over a long distance, I can get a different result than if I apply that same force over a short distance. Work can also be expressed in terms of pressure to talk about the work done on, or by, fluids.

There are some new symbols to learn when discussing these quantities.

Torque is represented by the τ . Impulse is represented by \vec{J} ; note that it is a vector quantity. Pressure, represented by the capital P, and work, I will use the capital W. Along the way in discussing these concepts, we will meet some other important ideas.

When we discuss torque, it will be important to introduce the idea of center of gravity. Torque is when you're interested about where the forces are being applied. If you're interested in where the forces are being applied, then you need to think about where does the force of gravity act. This is the idea behind center of gravity. When we discuss impulse, we will introduce the quantity momentum which uses a lowercase p, and you can see is also a vector. Momentum is a quantity connected to impulse, which we will revisit in greater detail in our unit on conserved quantities. The final quantity we will introduce in this unit is the quantity of kinetic energy represented by a capital K. Kinetic energy is connected to work, and again, we will revisit this quantity in our unit on conserved quantities.

Because of all the different quantities we're introducing in this unit, a nice way to organize them might be map.



So, we can think of the idea of forces from the last unit. So, a force applied at a point takes us to a torque, which we represent by the Greek τ , and the idea of torque is going to be connected to the idea of center of mass, as the center of mass dictates where gravity acts. We can also talk about forces being applied over an area, and this brings us to the idea of pressure, which again we represent by a capital P , and pressure will connect to our study of fluids. We can talk about forces being applied for some amount of time, and this brings us to the idea of impulse, J , which is connected to the idea of momentum as we'll see in this prep, which is represented by the lowercase p . And we can talk about forces being applied for a distance, bringing us to work, W , which is related to the idea of kinetic energy, K , and both will be related to our conserved quantities unit. Also, during this prep, you will see how work connects to the idea of pressure as work being pressure times the change in volume. This idea of a map to help you sort of organize all the information is a great study tool when studying physics, and I encourage you to maybe build your own using this as a core as you go through this unit.

Unit 4 Overview

This overview is based on umdberg / Reductionism and emergence (2015). Available at: [http://umdberg.pbworks.com/w/page/68371403/Reductionism%20and%20emergence%20\(2015\)](http://umdberg.pbworks.com/w/page/68371403/Reductionism%20and%20emergence%20(2015)). (Accessed: 23rd August 2017)

Science considers a wide variety of scales. In physics and biology we consider

- the nanoscale of atoms and molecules -- distances of nanometers (atomic size) and timescales of microseconds;
- the microscopic scale used in cellular biology -- distances of microns to millimeters and times of fractions of a second;
- the macroscopic human scale we are used to in everyday life -- distances of meters to miles and times of seconds to years;
- the global/deep time scale of ecology and evolution -- distances spanning thousands of kilometers and times of millions of years.

Physics considers scales beyond this including subatomic and even subnuclear structures and cosmological scales to the size of the entire visible universe and timescales of the lifetime of the universe.

We tend to analyze each system on its own terms using the concepts appropriate to the scale. But some of the most interesting scientific insights come from crossing scales. When we explain the properties of systems at one scale in terms of its component parts at a finer scale it's called **reductionism**. So when we analyze the conductivity of copper in terms of the bonding properties of copper atoms and how they share electrons from one atom in a crystal to the next, it's reductionism. When a patient experiences palpitations, sweating, dizziness, and headache, a caregiver might interpret this as occurring as a result of an imbalance in a chemical in the bloodstream -- insulin. Both of these explanations of a macro event in terms of microscopic properties are reductionism. We are looking at a system at a large scale and its characteristics are explained by something happening at a smaller scale.

We can consider the phenomenon of scale crossing in the other direction. If we are looking at a system at one scale, we might find that effects that seem very small add coherently to produce a dramatic and important effect when we step back and look at things at a larger scale. When the properties of a system at the scale we are considering have effects on a system of a larger scale, it's called ***emergence***, especially when the phenomenon might be almost un-noticable at the scale we are considering.

A physical example is polarization. If we put an atom in an electric field of typical macroscopic values (a few volts per meter), the electrons and the nucleus are pulled apart -- but only by a very tiny amount, perhaps 1 part in 100,000 of the atom's diameter. We might assume this is so tiny an effect that it can be ignored; but if every atom in a macroscopic object undergoes the same slight separation, the total effect might be that we can pick up the object, lifting it against gravity with the sum of the tiny electric forces we are exerting on each atom. The fact that we have so many atoms multiplies what looked to be a tiny effect. A similar phenomenon occurs in biology when there is a small survivability advantage to a mutation. One might not see any effect for many generations, but given thousands of generations, the gene pool of a population can be completely transformed by natural selection.

Of course, these are the same phenomenon, just looked at from different angles. But whatever scale we are considering, keeping these two perspectives in mind will help us to look for structures both at smaller scales that might provide reductionist explanations and at larger scales that might have emergent properties.

Unit 5 Overview

Exercise:



Problem: This unit overview is also available as a video [here](#).

This is our last unit of the course. Throughout this course, we have been progressing from more concrete concepts to more abstract. If you think back, we began with the concept of velocity, which people are familiar with from speedometers on their cars. Then, we move to the idea of force which people can physically feel, you can feel a push or pull, then we moved into “forces and...”, torque, impulse, work. These ideas are a little bit more abstract but rooted heavily in the idea of force. Energy is a bit more abstract of an idea, most people have some experience with energy from previous science courses, but trying to define what energy really is and getting used to thinking about it on a huge variety of distance scales can be a bit of a challenge. Now we are going to cover the one last idea of this course, which is yet still a little bit more abstract, this idea of entropy.

So, why are we covering entropy? Well, I have two answers. First, a practical answer. Many of you have seen entropy in a previous class, typically chemistry. For example, here is a slide from Chem 112 at UMass, and many of you will see this idea again. Entropy changes can help determine if reactions proceed spontaneously or not, and appears in the all-important Gibbs free energy. Typically, up to this point, you've either done qualitative arguments about entropy increases or decreases, or looked up standard entropies of formation in tables, but what is this quantity that you're using, in, say, Chem 112? Well, the typical answer in many courses that introduced the idea of entropy is disorder, but what is disorder? How do you quantify it? And disordered by whose perspective? Disorder, that's a very nebulous idea. Who gets to decide what's an ordered state and what's a disordered state? And it turns out that this definition isn't even correct, so I

think that if you're going to deal with the topic, as much as many of you will deal with the idea of entropy, you should know what it is.

There's another, second more physicist answer as to why I think we should cover entropy. In a sense the whole discipline of physics, not just this course, but the whole discipline of physics, from this course to the very frontiers of modern research can really be boiled down to a few key ideas.

Forces

$$\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$
$$\vec{F}_{1 \rightarrow 2}^X = -\vec{F}_{2 \rightarrow 1}^X$$

Energy

$$\Delta E = Q - W$$

Entropy

$$S = k_B \ln W$$
$$\frac{\Delta S}{\Delta t} \geq 0$$

Forces and Newton's laws, here written as $\Delta p/\Delta t$ and Newton's third law, energy and its conservation, and the last one is entropy. So, in this green box, we have the definition of entropy here and what's known as the second law of thermodynamics. No matter how much physics you study, you're still looking at how different objects respond to forces, how energy is conserved, what is the entropy in the system and how is it changing. Since forces, energy, and entropy are three of the fundamental pillars of physics, I feel it would be remiss to leave entropy out.

So, what is entropy then? If it's not disorder what is it? Well, let's think about what is going on at the microscopic level. At the microscopic level, things are of course always changing. Molecules are moving around, chemical reactions are always proceeding, but many of these changes do not affect the microscopic picture. For example, from chemistry, when you add two reactants, the reaction never really stops, we just reach an equilibrium point where the number of reactions going in one direction equals the number of reactions going in the other direction. The molecules are constantly interacting with each other, forming bonds, dissociating bonds. At the microscopic picture, we have a hubbub of activity but at our macroscopic scale we don't see a lot of change. So, what do I mean when we say we don't see a lot of change at the macroscopic level? We mean the total energy in the system, the pressure, if it's a gas, the volume, all these

types of quantities that are easily measured in macroscopic level. Entropy is the number of ways that I can rearrange things on the microscopic level, which we call the number of microstates, which we will indicate by a letter W (no, this is not the work W , this is a different W , conventions are conventions). So, how many ways can I rearrange things, how many different microstates, are there that don't change the macroscopic world: that is what entropy is. So, it turns out that counting the number of ways energy can be distributed microscopically while leaving the macroscopic world unchanged has important implications, which is weird when you stop and think about it. I mean, the number of possible ways I can arrange things seems like a very theoretical construct, and to make matters more interesting, the numbers we'll be dealing with will be ginormous. 10^{23} is not a surprising number to deal with when you start talking about the number of ways to arrange energy amongst all the molecules in a room. These types of numbers start to appear. That is a one with a mole of zeros after it. That's a big number. These huge and seemingly theoretical numbers are the basis of what entropy is.

So, what do I want you to get out of this unit? I want you to have a beginning of a grasp of what entropy is and how we can quantify it. I want you to understand why some processes proceed spontaneously due to entropy considerations. And finally, I want you to understand how entropy can drive processes in a way that results in final states that might seem more ordered to us, but are in actuality an increase in the number of microstates when you consider the whole system. The following prep videos and reading and homework problems will lay the groundwork of some of the basic mathematics you will need to study this topic. This concludes this video.